NOVEL TRACKING LASER RANGE FINDER(T-LRF)

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ABSTRACT

PLX's Tracking Laser Range Finder (T-LRF) uses PLX's core Monolithic Optical Structure Technology™ (M.O.S.T), combined with PLX's Active optics precision technology, to create a compact high-performance tracking solution in a highly integrated system. Once the target is acquired, the T-LRF locks onto the target and feeds real time 3-dimensional bearing information to the host system, enabling further actions against the target. It can do this at long ranges against small, fast moving, hard to track targets such as consumer and military drones. The T-LRF can be fitted onto a Counter-UAS system by replacing the conventional LRF module. A prototype is available to demonstrate the performance of the T-LRF. PLX's solution can provide sub arc second accuracy in the harshest operating conditions, making the Tracking Laser Range Finder a game-changing technology in the security, defense, and combat arena.

Keywords: Counter-drone systems, Laser ranger finder, Counter-UAS, Drone tracking, PLX, Laser tracking, Monolithic Optical Structure

INTRODUCTION

Founded in 1955, PLX has been producing highly accurate optical domes, lenses, prisms, and mirrors. With the recent acquisition of Reflex Imaging in 2021, PLX has acquired the knowledge and expertise to integrate beam steering technology into the product range. PLX has several patented technologies that utilize commercial Micro Electro-Mechanical Systems (MEMS) optical devices in innovative ways. PLX's Tracking Laser Range Finder (T-LRF) is a new patent pending technology. Using PLX's core Monolithic Optical Structure Technology™ (M.O.S.T) [1] with PLX's precision beam steering technology, it creates a compact high-performance tracking solution in a highly integrated system package by combining tracking and range finding in one system.

With the integrated scanning and tracking functions, T-LRF eliminates the need for video-based tracking devices, and rapid movement of motorized platforms. This reduces the system complexity and ensures enhanced reliability. The T-LRF can also out-perform other technologies used for tracking, such as LiDAR and Radar, with improved accuracy and dynamic performance with reduced size and power requirements while operating under harsh environmental conditions associated with defense and aerospace applications. This technology can be used for drone mapping and Counter-UAS systems as an improvement over the conventional LRF module.

1.1 Novel Tracking Laser Range Finder (T-LRF)

The T-LRF is designed to provide real time, high accuracy bearing and range data of a tracked target or multiple targets to the host system.

This technology enables significant benefits to applications which require precise tracking of fast-moving objects, for example tracking drones, tracking debris in orbit for removal or defensive systems to counter incoming projectiles such as missiles.

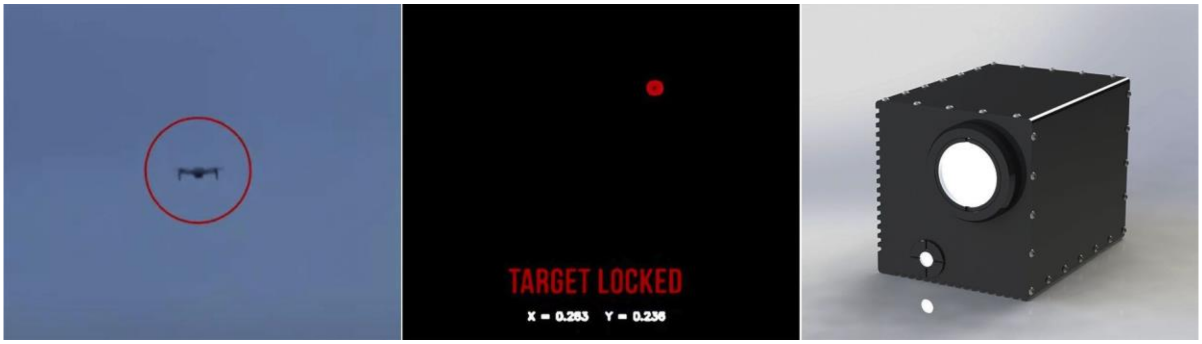

Figure 1 The T-LRF preforming drone tracking

1.2 Working Mechanism

The working mechanism of the T-LRF involves several critical components and technologies as shown in

Figure 2. A high repetition rate pulsed laser is directed by a Micro-Electronic Mechanical System (MEMS) scanning mirror to scan for reflections within its field of view. Once the target is acquired, the T-LRF locks onto the target and tracks it using a nutation pattern or directional feedback from the receiver, feeding bearing information back to the host system. Range information is calculated by measuring the time of flight (TOF) of the laser pulses. This together with the bearing information creates an accurate position of the target, which allows the appropriate electronic or ballistic countermeasures to disable or destroy the target.

$$D = c\frac{\Delta t}{2}$$

D: The distance of the object

c: Speed of Light

Δt: Time of Flight

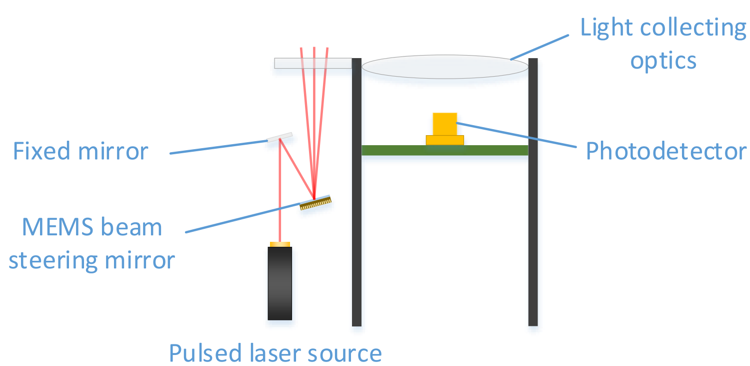

Figure 2 The working mechanism of the T-LRF

The T-LRF can perform accurate tracking of fast-moving targets with <2ms latency. It generates real time ballistic quality bearing, ranging and trajectory information for targets up to 10km range.

1.3 Critical Components and Technologies

There are three critical components and technologies implemented into the T-LRF system to enable the performance.

1.3.1 MEMS Beam Steering Mirrors Technology

The first critical technology of the system is MEMS beam steering mirrors, which involves accurately and rapidly steering the beam from a laser source. MEMS beam steering mirrors are particularly suited to this kind of application as they are compact, have high bandwidth, low power consumption, and have high repeatability between devices.

The mirrors on these devices are small and lightweight (up to 7mm diameter typically) that can tip and tilt rapidly. Usable bandwidth for steering these in non-resonant mode is up to 2kHz for small mirrors and around 250Hz for the largest mirrors depending on the scan angle. This far exceeds any conventional motor driven gimbal system for directing electro-optic devices such as cameras or laser rangefinders.

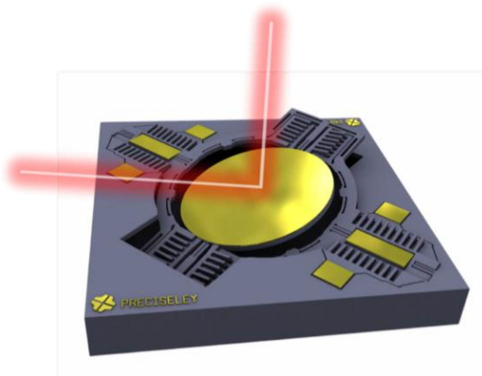

Figure 3 MEMS mirror

Accuracy of these devices varies depending on the manufacturer, actuation technologies and positional feedback mechanisms. The T-LRF uses commercially available devices with proprietary sensing technologies to significantly improve the positional accuracy of these devices, currently achieving ±10 arcseconds with a low-cost resonant MEMS mirror device. PLX is currently working on a device that achieves ±1arcseconds.

MEMS beam steering mirrors are silicon-based devices, fabricated from silicon wafer using the same processes as conventional semiconductor integrated circuits. This makes it possible to fabricate intricate microstructures in a very repeatable, scalable, and low-cost way.

1.3.2 High Repetition Rate Laser

The second major component of the system is a high repetition rate pulsed laser.

Conventional Laser range finders typically operate at a few Hz and are intended for static or slow-moving targets. However, they achieve exceptional range (up to 20km typically) by using short laser pulses with intense peak power (Up to 100kW in some cases). The power of these device is sufficient that coherent detection is generally not required.

LIDAR systems by contrast use a much higher repetition rate (100’s of kHz to MHZ typically) to achieve the necessary spatial resolution. In pursuance of keeping the eye-safety aspect and to keep the average power low, the laser pulse intensity is much lower, resulting in a range of only a few hundreds of meters. Coherent detection would reduce the refresh rate or spatial resolution of these devices, therefore is generally not used.

Combining the advantages, the High Repetition Rate Laser in T-LRF has a high enough repetition rate (>5kHz) for coherent detection and real time tracking while providing sufficient peak power (>5kW) to achieve long ranges of up to 10km. By varying the pulse repetition rate or pulse pattern, it is possible for multiple T-LRFs to operate in proximity without interfering with one another.

Figure 4 Pulsed Laser Module

1.3.3 Monolithic Optical Structure Technology™ (M.O.S.T)

PLX's patented Monolithic Optical Structure Technology™ (M.O.S.T) has been developed to permanently incorporate multiple optical elements (such as mirrors, beam-splitters, lenses, freeform optics, diffractive elements, prisms, or active optical devices) of a complex optical configuration, into a compact, lightweight monolithic structure. The optical elements are made from CTE-matched optical materials such as fused silica, low expansion borosilicate, ULE, BK7, ceramics and/or metals. This combined with PLX's proprietary invariant optical technology, minimizes the beam deviation to sub arcsecond accuracy with minimal variation of optical specifications in the most extreme environments, where large thermal excursion, high shock and vibration are the typical operating conditions.

An integral part of the M.O.S.T. is the mounting to higher level assemblies without inducing any stresses, distortion or other forces to the M.O.S.T. unit. PLX has several techniques used for this, ranging from single point mounting/connection to the use of polymeric materials to provide isolation from stresses while still maintaining proper positioning of the assembly. The properties of the polymeric materials can vary depending on how they are incorporated, and this must be carefully considered as part of the finite element analysis that is performed on these systems.

Figure 5 PLX Monolithic Optical Structure Technology™ (M.O.S.T) structure

1.4 T-LRF Operation Modes

Enabled by the novel technologies integrated together, the T-LRF can operates in four distinct modes, each of which is associated with a particular function.

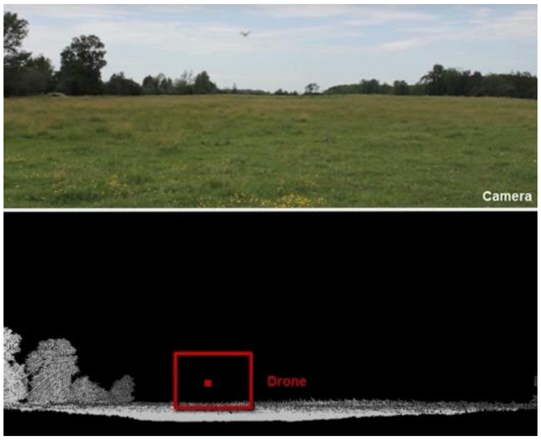

Figure 6 The T-LRF working during both day and night

1.4.1 Laser Rangefinder Mode

The first mode allows the user to operate the T-LRF as a conventional laser range finder. The refresh rate on the range readings can be traded for range by increasing the number of pulses used for each range calculation. As the MEMS mirror can be steered to any arbitrary angle, this allows the host to select a target range without having to physically move the T-LRF or the host platform if the target is within the Field of View (FOV).

Alternatively, the host could steer to various bearings in sequence within its FOV in the scenario where the host needs to range/track multiple targets (a drone swarm for example).

Since the pulse train pattern can be arbitrary there is potential for this to be also used for laser designation applications in static pointing or tracking modes.

Figure 7 Drone swarm

1.4.2 Target Searching Mode

The second mode is target search mode. In this mode, the T-LRF scans a defined area looking for reflections with sufficient strength and within its range gate. It is anticipated that the host system will supply the T-LRF with approximate range and bearing based on radar or long-range video camera data to reduce acquisition time.

With the objective of assisting the host in determining that the T-LRF has acquired the correct target, continuous intensity and range data is fed back for comparison to live video/radar data. At any time, the host can designate a specific target bearing/range to track based on this data, or the T-LRF can automatically switch to tracking mode once a valid target is detected based on the intensity/range data.

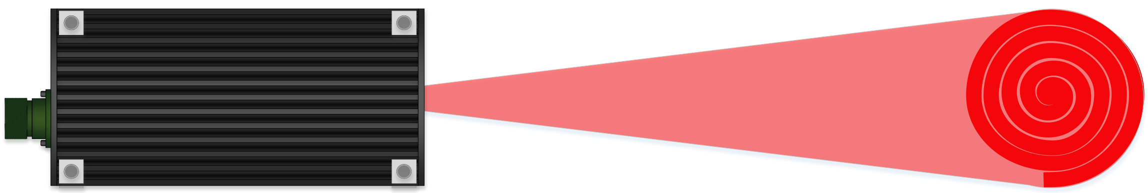

Figure 8 T-LRF in Target Searching Mode

1.4.3 Target tracking Mode:

Once a valid target has been acquired, the T-LRF changes to tracking mode, either automatically or at the direction of the host system. In this mode the system attempts to keep the laser consistently at the target.

The MEMS mirror can nutate the laser and use directional feedback from the receiver optics to determine if the laser is pointed at the target centroid or if it is off center. Based on the receiving reading, the centroid bearing of the target is fed back to the host system, and the T-LRF sets the mirror position demand to correct any error.

As the laser is continuously pulsing it is also generating real time range data to go with the bearing data from the mirror. Each reading is accurately time-stamped against a synchronization input or output signal, this allows the host system to accurately determine the targets position in 3D space, as well as its speed and trajectory from multiple readings.

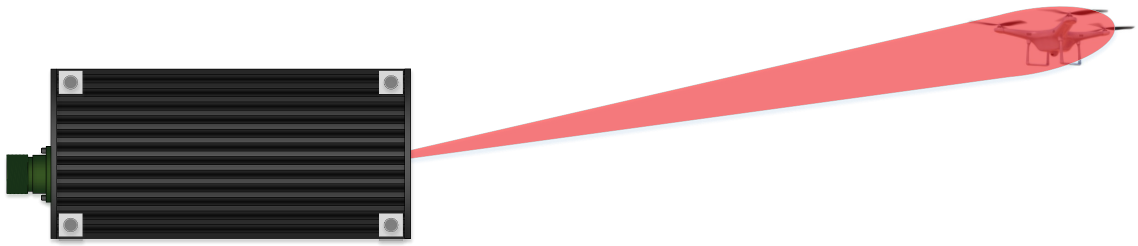

Figure 9 T-LRF tracking a drone

1.4.4 Dynamic track mode:

Several targets within the FOV can be tracked in sequence, trading refresh rate for multiple target tracking

It can also be used to provide ranging and bearing information for large number of static/slow moving targets in the FOV.

COUNTER-UNMANNED AIRCRAFT SYSTEMS (C-UAS)

1.5 Case Study: Counter-UAS Application

The first application of the T-LRF will be for tracking of small, fast-moving drones. While this could potentially be used for drone mapping applications, perhaps the most pressing need for this technology is within Counter S-UAS applications (Small Unmanned Aerial Systems).

The proliferation of small, cheap drones is the “most concerning tactical development” since the rise of the improvised explosive device in Iraq, Marine Gen. Kenneth McKenzie, who helms CENTCOM, said in prepared remarks at the Middle East Institute in February 2021. “I’m not just talking about large, unmanned platforms, which are the size of a conventional fighter jet that we can see and deal with by normal air defense means. I’m talking about ones you can go out and buy at Costco right now for $1,000.” McKenzie said.

Small drones can pose a threat from not only malicious use both domestically and in military bases and forward positions worldwide, but also from accidental or negligent misuse near airports, stadiums or other soft/sensitive sites. Regardless of the countermeasure technology, these drones need to be detected, tracked and identified by counter-UAS systems.

Figure 10 A small ISIS drone captured by Iraqi police

1.6 T-LRF Benefits to Counter-Unmanned Aircraft Systems (C-UAS)

The T-LRF can be used on Counter-UAS systems as a replacement to a conventional LRF module for ease of integration. With the integrated scanning and tracking functions, it eliminates the need for video-based tracking devices and rapid movement of motorized platforms. This greatly reduces the system complexity and ensures enhanced reliability.

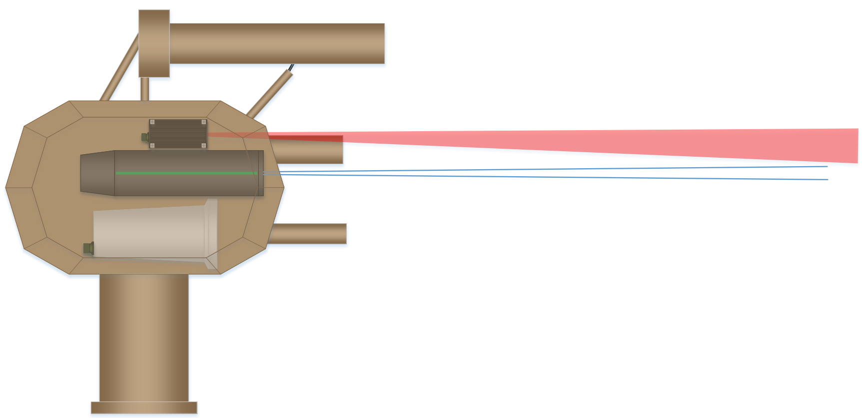

Figure 11 T-LRF implementation on C-UAS system

The T-LRF confers the following benefits to a C-UAS system.

- **Superior tracking performance:** ~100x faster than gimballed/motorised platforms using MEMS technology.
- **System simplification:** Eliminates the need for video-based tracking hardware/software, reducing system power consumption, cost and complexity, as well as dynamic requirements of the Electro Optical Director (EOD) host system.
- **Automated target identification:** Improved tracking performance allows the LRTV to capture high resolution images of fast-moving targets, enabling automated object identification/classification.
- **Ballistic quality data:** The real time tracking and precision of the T-LRF generates ballistic quality position and trajectory data.

- **Simple integration:** The T-LRF replaces the conventional LRF module with significantly enhanced function. This minimizes the system cost/weight/power impacts of integrating this technology
- **High reliability:** The only moving part is the MEMS mirror which thanks to its monolithic, low friction design has an extremely long life when compared to motorised platforms. This reduces wear to the host EOD by minimizing small frequent movements to track the target.

Parameter	T-LRF	Lidar (Neptec P500)	Video tracking	RADAR
Field of view	±5°	±45°	1.7° x 2.6°	360°
Range	2km-10km	500m	1000m	10km
Accuracy	±10µrad, ±30cm	Not available	±0.1mrad	>±20mrad
Latency	<1ms	>200ms (estimate)	>30ms	>250ms
Refresh rate	1kHz	5Hz (estimate)	50Hz	4Hz max
Wavelength	1550nm	1550nm	visible	17GHz

Table 1 Comparison of technologies

Table 1 shows the comparison of competitive technologies, where the T-LRF exhibits its unique advantages towards C-UAS system.

CONCLUSION

PLX's Tracking Laser Range Finder (T-LRF) combined with PLX's core Monolithic Optical Structure Technology™ (M.O.S.T), provides sub arcsecond accuracy in the harshest operating conditions, making T-LRF a game-changing technology in the security, defense, and combat arena. This technology can be applied to drone mapping and Counter-UAS systems as an improvement. As noted, the benefit of this system allows the T-LRF to lock onto the target and feed real time 3-dimensional bearing information to the host system, enabling further actions against the target.

[1] US Patent 6,141,101